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Ultrasound-guided Needle nerve contact positions detection in Regional Anaesthesia using Needle tip force and Opening injection pressure

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Abstract. Ultrasound imaging guidance has been widely used in peripheral nerve block to guide the anaesthetist to insert the needle and observe injection fluid diffusion. However, needle-nerve contact(NNC) positions visualization is difficult to achieve because of requirement of high image resolution and expert. To better guide the anaesthetist to predict the distance from needle to nerve and reduce the needle trauma, we attempted to use Needle tip force(NTF) and Opening injection pressure (OIP) to identify the NNC positions under ultrasound guidance. The relationship between OIP and NNC, NTF and NNC, NTF and OIP is unclear now, and we conducted a prospective, observational study to define the relationship. In this study, we designed a multi-function block needle and built a real-time NTF and OIP measurement which could trace and record NTF and OIP data in the simulator sciatic nerve. NNC positions were divided into three distinct NNC positions: Pre-NNC, First-NNC, Forceful-NNC using ultrasound guidance image. We statistically analysis NTF, OIP in the three NNC positions, and the results indicate the NTF differentiate in three NNC positions($p < 0.001$), OIP differentiate as well ($p < 0.001$) and the NTF has a highly positive with the OIP in the same NNC positions with Pearson correlation 0.62.

1. Introduction

Regional nerve blocks provide anaesthesia to limbs and avoid general anesthesia with the consequent risks [1]. In practice, needle insertion and dispersion of anesthetic are performed under ultrasound guidance (UGRA) [2-4]. UGRA has been an important guidance method compared with the blind insertion [5], and was commonly used in regional anesthesia to safety and relief the pain for the patients[6]; however the UGRA also has limits, the success of the regional anesthesia depends on the high expert and image resolution[2]. Poor visualization of NNC positions under ultrasound guidance may lead to nerve injury or failure of anaesthesia because of the incidence of NNC severely in regional anaesthesia[3, 7, 8], and it has been reported that nerve inflammation and injury occur after high opening injection pressure and intraneural injection or forceful needle nerve contact [9-11].

In order to reduce the needle trauma, relieve patients pain and decrease the difficulty for the trainee in regional anesthesia, we studied the possibility that the Needle tip force(NTF), Opening injection pressure(OIP) could be provided to the anaesthetist to guide them to detect the Needle nerve contact



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pressure parameters in the clinical practices; haptic palpation has been utilized to support multiple layers of anatomy and a pulse force algorithm for simulation of an arterial pulse [12]; needle insertion force also studied a lot to model the needle insertion force during the needle insertion tissue procedure [13, 14], NTF has been used for the interactive simulation and robotic percutaneous therapy [15]. High OIP study for patients has been conducted to detect NNC during brachial plexus blockade [16, 17] and high OIP associated with Needle-Nerve and Needle-Fascia Contact during femoral nerve block was observed recently [18]. The success of epidural block depends a lot on the detection of the epidural space [9]. All the above research results lead us to study the relationship between NTF and NNC, OIP and NNC, NTF and OIP.

In this study, we contributed for three ways: (1) designed the multi-function block needle and built the NTF and OIP measurements system for regional anesthesia, (2) used the real-time NTF to study relationship between the NTF and the NNC positions, and (3) used the OIP to study relationship between the OIP and NNC positions. Our final aim is to build a robotic adaptive control regional anesthesia simulator system to reduce the anesthesiologist's workload and decrease the requirement of anesthetist skills.

2. Material

2.1. Multi-functions block needle

A 150mm 21g insulated nerve block needle (B.Braun, Sheffield, England), was placed through the annular force sensor (LC8100-200-10, Omega, UK) as the Figure 1 shows.

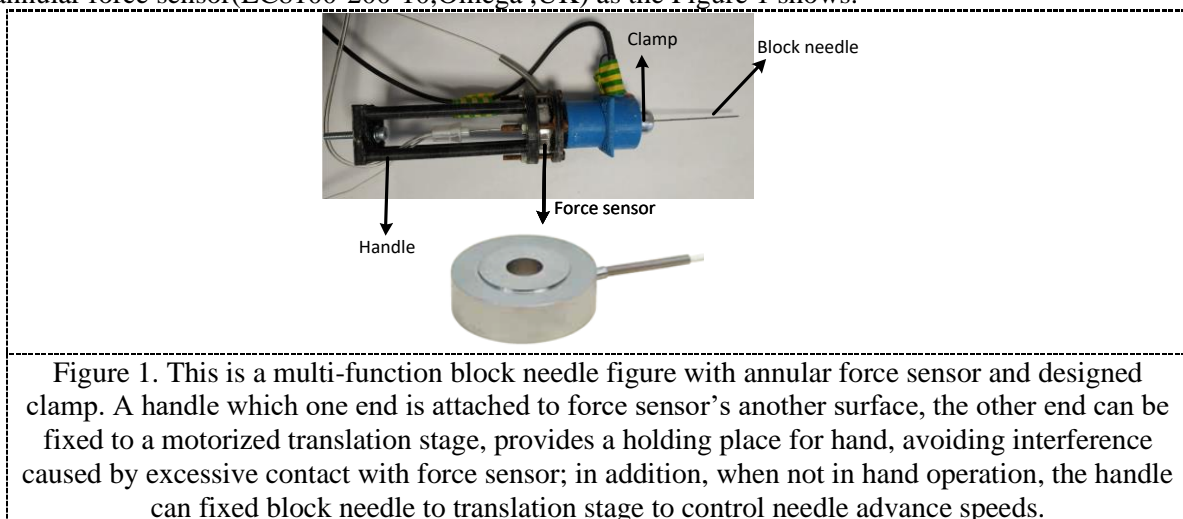


Figure 1. This is a multi-function block needle figure with annular force sensor and designed clamp. A handle which one end is attached to force sensor's another surface, the other end can be fixed to a motorized translation stage, provides a holding place for hand, avoiding interference caused by excessive contact with force sensor; in addition, when not in hand operation, the handle can fixed block needle to translation stage to control needle advance speeds.

This multi-function needle could have several functions:

- measure the real-time NTF feedback by the force sensor.
- provide the injection interface to connect with the injection pump, pressure sensor and OIP monitor.
- change the needle insertion directions and speeds by fixing the needle handle in the motor stage.
- change the block needle length outside by adjusting the clamp.

2.2. Translation motor stage

Three-degree translation motor stage is composed with two servo controller (TDC001, Thorlabs, US) and one continuous rotation component (CR1, Thorlabs, US). Servo controllers provide the X and Y direction motor driver, and rotation component provided the X rotation. This schematic of three-degree translation motor stage was shown in Figure 2, and we adjust the needle positions relative the experiment tissues by adjusting the X and Y displacements and X rotation is used to change the needle insertion angle, which is important to better show the needle shaft and tip image to keep the ultrasound probe and needle insertion shaft in line. The needle insertion speed range of this motor stage is between 0 and

2.4mm/s, and this speed could be adjusted by the software Kinesis PC software (Kinesis, Throlabs, US). This translation motor stage make it possible to insert the block needle at constant speed and desired displacement.

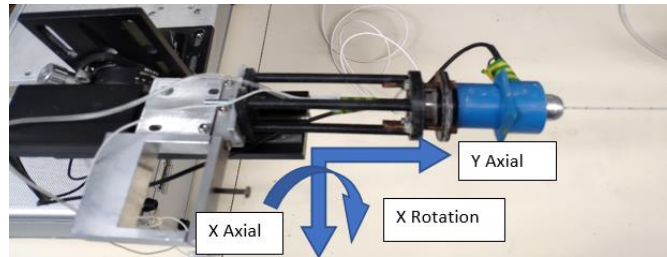


Figure 2. Schematic of three-degree translation motor stage.

2.3. Pressure sensor and measurement system

The pressure sensor (PendoTECH, Princeton, New Jersey) is adopted to measure liquid pressure connecting with the needle infusion tube and the pressure-time data were obtained using an electronic pressure monitor (PendoTECH, Princeton, NJ) coupled to a computer via a conversion board (PressureMAT, USA). Meanwhile, we build Labview Program in the computer to record and show the OIP-time data in graph and give a mark if the OIP value is over the pressure threshold 15psi but not stop the injection, this value is regarded as OIP threshold to cause nerve damage in brachial plexus blockade [16]. A 50mL standard syringe is clamped within injection pump (PHD2000, Harvard Apparatus, US), employing a microcontroller which controls a small stepped motor that drives a lead screw and pusher block, is used to automatically drive syringe at a preset fluid volume and flow rate.

2.4. Force sensor and measurement system

Force sensor LC8100 (Omega, UK) with a through-hole and two surface design, capacity of 10lb (44.452N). Force measurement system is composed with the force sensor, acquiring board, computer. Force sensor is connected with the acquiring board cDAQ-9174 (National instruments, US), acquiring board connected with the computer running the Labview force measurement program, and the real-time force data was recorded and shown. With extremely low-profile and compact design, the force sensor is convenient to use in regional anesthesia to detect NTF feedback real-time.

2.5. Ultrasound-guided image system

A SonixTablet ultrasound machine (BK Ultrasound, Herlev, Denmark) with the 5MHz to 14MHz transducer is used to record the simulated regional anesthesia ultrasound image, when the image is clear to identify the three NNC positions, we inject the infusions and observe the OIP value and fluid spread.

All the above apparatus was used to build NTF and OIP measurements system during simulator regional anesthesia. The force sensor detected real-time NTF feedback acting on the needle, and force measurement system construct continuous force tracings and record force-time data; the pressure sensor detected the real-time OIP generated by flow of fluid against tissue, and constructed to continuous pressure tracings and recorded by pressure measurement system. The whole process of this measurement system work turn: needle inserted into the lamb upper sciatic nerve, and when needle tip reached the specific NNC positions, validated by an image expert for the clinical ultrasound machine, then syringe pump started to receive command to inject fluid automatically at preset liquid volume and rate. Ultrasound-guided imaging system guided the needle insertion and fluid injections all the time.

3. Method

We conducted two studies step by step: force measurement system validation, simulated sciatic nerve blocks on lamb upper leg. Force measurement validation study aimed to validate the measurement force value by comparing with commercial force measurement. Pressure measurement system was a commercial measurement which has been used and validated. Simulated sciatic nerve block study was conducted to observe the relationship between NTF and NNC, OIP and NNC in the condition of

automatic needle insertion and injection condition, avoid the influence of human operation, at the three specific location: Pre-NNC (Needle tip advanced to 1-2mm from the First-NNC), First-NNC (Needle tip slightly indenting the epineurium of nerve), Forceful-NNC (Needle tip advanced another 10mm from First-NNC, much indenting the epineurium of nerve).

3.1. Force measurement system validation study

The Force measurement system was calibrated using a Materials Testing Machine (model 300ST- Tinius Olsen Testing Machine Company, UK) capable of testing loads up to 50N. We zero the Testing Machine Model 300ST force measurement value and position first, and increase load on force sensor almost every 2N interval until the force value reached 45N, then we record both the Testing Machine force value and our force measurement system value synchronize.

3.2. Simulated sciatic nerve blocks on lamb upper legs study

Needle insertions and fluid injections were performed under real-time guidance of ultrasound machine SonixTablet (BK Ultrasound, Herlev, Denmark) with a 5 MHz to 14MHz transducer on three lamb upper legs. Total 60 sites of sciatic nerve were inserted and injected. The needle was clamped at the motor stage and can move forward or backward at given speed and distance; ultrasound probe was hold by transducer holder and lamb upper leg was placed on the up and down platform, the simulated nerve blocks on lamb upper leg experiment setup is shown as Figure 3.

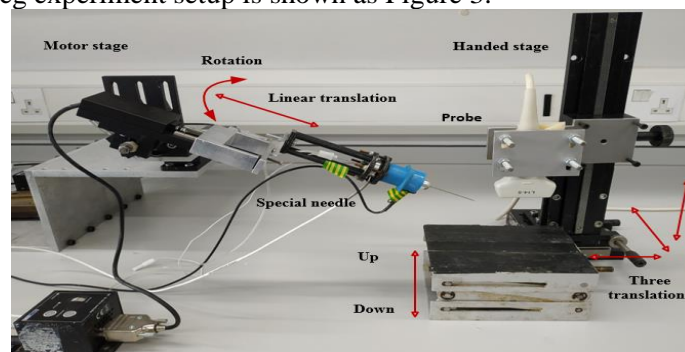


Figure 3. Simulated sciatic nerve blocks on lamb upper leg setup.

In each insertion, the needle was orientated within the line of the transducer elements, and angled in the direction of the target nerve. Water was filled in the syringe and injected in this experiment. The needle advancing speed was set as 1.5mm/s, fluid injection volume 0.5mL, fluid injection rate 6mL/min. This injection rate and needle insertion speed were set based on common clinical practices [20]. Force and Pressure data were recorded when the ultrasound machine show clear image to identify the needle nerve contact position.

Our aim was to find the relationship between OIP and NNC, NTF and NNC. Therefore, with the bevel always oriented downward, the needle was advanced and positioned sequentially in the 3 positions to inject fluid as follows (Figure 4):

- (a) Needle tip advanced to 1-2mm from the nerve ("Pre-NNC") (Figure.4A)
- (b) Needle tip slightly indenting the epineurium of nerve ("NNC") (Figure.4B)
- (c) Needle tip advanced another 10mm from needle-nerve contact, much indenting the epineurium of nerve ("Forceful NNC") (Figure.4C)

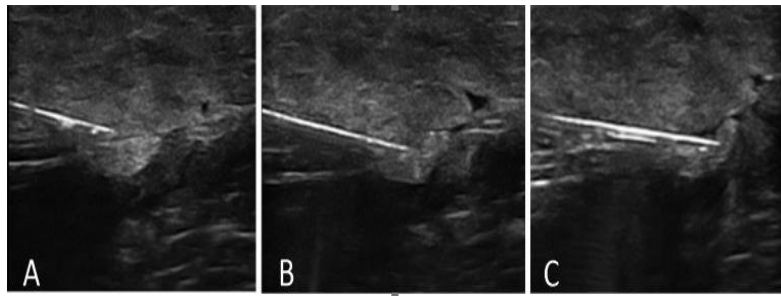


Figure 4. Ultrasound images at three NNC positions: (A) Pre-NNC, (B) First-NNC, (C) Forceful – NNC.

The Statistical Package for the Social Sciences (version 25.0; SPSS IBM,) was used to analyse the relationship between NTF and NNC, OIP and NNC by using the ANOVA analyses, NTF and OIP by using linear mixed model. P values less than 0.05 were considered statistically significant.

4. Results

4.1. Force measurement validation results

We compare the difference between our force measurement and the commercial force measurement which was regarded as known standard. The calibration result is shown as Figure 5 and it validated that our house made force measurement could be used in this experiment.

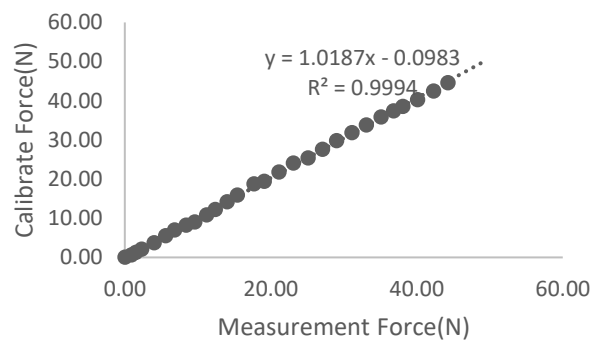


Figure 5. Force measurement validation results.

4.2. Simulated nerve blocks on upper leg results

A typical Force and Pressure data was recorded in a simulated lamb upper leg sciatic block as Figure 6 shown. Force and pressure data were superimposed onto single graph with two y-axes. The x-axis represented synchronized time.

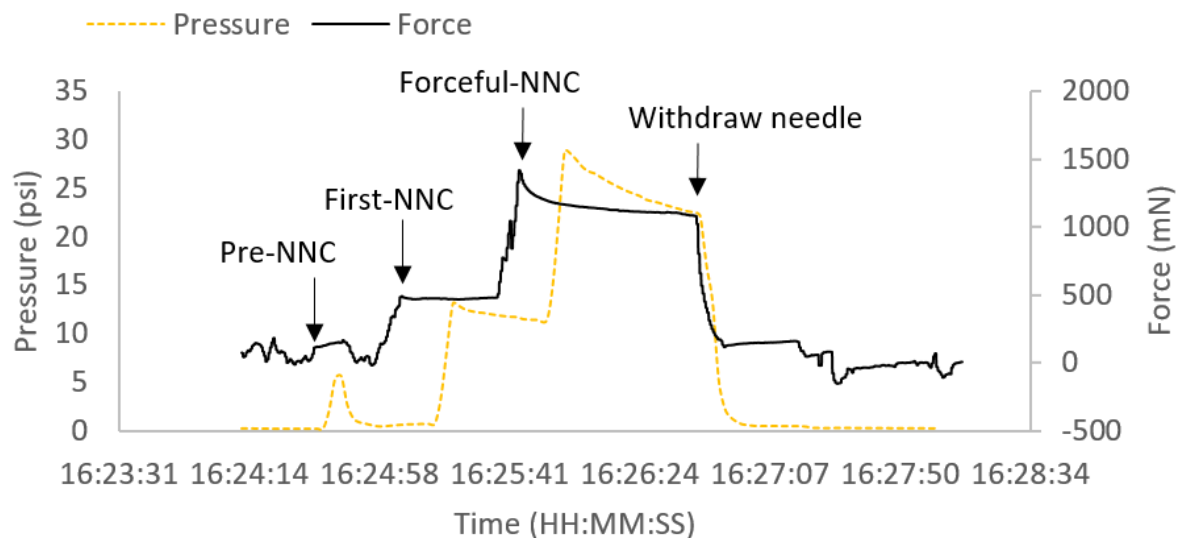


Figure 6. Force and pressure result in a simulated lamb experiment.

NTF and OIP in three different NNC positions were presented as Mean \pm SD as Table 1 shows. Bivariate Correlations was used to analyze the correlation between NTF and NNC, OIP and NNC, NTF OIP. Linear mixed model was used to compare differences of NTF and OIP in the three NNC positions.

Table 1. Statistical result of NTF and OIP in three NNC positions.

NNC positions	NTF (mN)	OIP (psi)
Pre-NNC(n=56)	260 \pm 302	6.7 \pm 2.0
First-NNC(n=60)	551 \pm 629	10.0 \pm 3.4
Forceful-NNC(n=52)	1632 \pm 1190	16.3 \pm 4.3

*n represent the used successful samples in three NNC positions

Type III Tests of Fixed Effects showed a difference in NTF between NNC ($P < 0.001$) and a difference in OIP between NNC ($P < 0.001$). Post hoc Bonferroni analysis revealed that NTF in the Forceful-NNC position was higher compared with that in the First-NNC position (mean difference, 1128 \pm 129mN; $P < 0.001$; 95% CI, 827mN to 1430mN) and that in the Pre-NNC position (mean difference, 1421 \pm 129mN; $P < 0.001$; 95% CI, 1109mN to 1732mN); OIP in the Forceful-NNC position was higher compared with that in the First-NNC position (mean difference, 6.5 \pm 0.6psi; $P < 0.001$; 95% CI, 5.1psi to 7.8psi) and was higher compared with that in the Pre-NNC (mean difference, 3.4 \pm 0.6psi; $P < 0.001$; 95% CI, 2.1psi to 4.7psi). Pearson correlation between NTF and OIP was 0.62.

5. Discussion

We designed multi-function block needle and built the NTF and OIP measurement system under the ultrasound guidance; it could automatically insert needle, inject fluid and record the NTF and OIP in the real-time, which can provide device support for the robotic assistance in regional anaesthesia in the future [21]. The use of robots in regional anesthesia has been evaluated in recent years [22], when the commercial robotic regional anaesthesia come true combined with remote control technology in clinical practice [23], anaesthetist could operate remotely in the different places with the patients in the future.

This study results demonstrated a clear relationship between NTF, OIP and the NNC positions in the simulated sciatic nerve blocks on lamb upper legs. The results guide us to consider the possibility that both NTF and OIP could be regarded as the potential parameter to identify the NNC positions during the regional anaesthesia except the ultrasound guidance[2], and high OIP has been reported to associate

with needle nerve contact to identify the success of the regional anaesthesia [16,18]; NTF guidance ,adding a force sensor in clinical needle to measure, could also be took as another potential way to guide clinicians in their clinical practice; and NTF guidance has several advantages that it doesn't change any current patients feeling other than changing the structure of block needle ;the force sensor was cheap compared with expensive commercial high resolution image experiment. More prospective observation study should be conducted in the thiel cadaver and patients in the future.

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